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SHORT COMMUNICATION

DISCUSSION: 'HYDROLOGICAL MODEL OF PEAT-MOUND FORM WITH VERTICALLY VARYING HYDRAULIC CONDUCTIVITY' BY ADRIAN C. ARMSTRONG

ANDREW J. BAIRD

Department of Geography, University of Sheffield, Winter Street, Sheffield, S10 2TN, U.K.

AND

SIMON W. GAFFNEY

Field House, Clays Lane, East Worldham, Alton, Hampshire, GU34 3AD, U.K.

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ABSTRACT

In this comment we argue that the premise on which the peat mound model developed by Armstrong (Earth Surface Process and Landforms, 1995, **20**, 473–477) is based, that hydraulic conductivity shows an exponential decline with depth in bog peats, is unsound. Empirical evidence in the literature for such an exponential decline is less sound than Armstrong suggests. In addition, Armstrong's suggestion that the hypothesis of Baird and Gaffney (Earth Surface Processes and Landforms, 1995, **20**, 561–566) supports an exponential decline is shown to be erroneous.

KEY WORDS peat mound model; exponential decline of hydraulic conductivity; methane gas bubbles

In this comment we argue that the premise on which the peat mound model by Armstrong (1995) is based, that hydraulic conductivity shows an exponential decline with depth in bog peats, is unsound.

In his recent paper, Armstrong (1995) presents an interesting development of the groundwater mound model used to predict raised mire topography. He shows how monotonic changes in hydraulic conductivity with depth in a mire can affect the steady-state water table position and therefore, using Ingrams's (1982) theory that the position of a mire surface is controlled by the position of the water table, the shape of a mire. Most previous attempts at modelling water tables in mires have used simple analytical equations which require specification of a single value of hydraulic conductivity for an entire mire. This is obviously unrealistic and Armstrong is to be applauded for using a more flexible numerical approach in which spatial variability of hydraulic conductivity can be incorporated.

The basis of Armstrong's development is that the hydraulic conductivity of peat within a mire decreases with depth according to an exponential function given by Youngs and Goss (1988). Armstrong notes that such exponential decline appears to have considerable generality in mineral soils but acknowledges that the evidence from organic soils is more equivocal. He suggests that evidence for an exponential decline in peat hydraulic conductivity with depth is given by Boelter (1965), Sturges (1968) and Päivänen (1973), while noting that the data of Kneale (1987) and Chason and Siegel (1986) show no systematic variation of hydraulic conductivity with depth. We disagree with Armstrong that the results of Sturges (1968) support an exponential decline of hydraulic conductivity with depth. Sturges (1968) measured hydraulic conductivity in well-decomposed peat in a headwater bog peat using piezometers at two depths (46 cm and 91 cm below

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the surface). Five measurements were taken at each depth. Sturges found that two of the piezometers installed at 91 cm gave very fast rates of flow and attributed this to flow through fissures in the peat. Even when these values are removed, the mean of the hydraulic conductivities at 91 cm is only 33 per cent lower than the mean at 46 cm. If anything, Sturges's results suggest that hydraulic conductivity increases with depth in the peats he observed, although sample sizes of five and three are insufficient to demonstrate significant differences.

We agree with Armstrong that the research of Boelter (1965) and Päivänen (1973) provides evidence in support of an exponential decline in hydraulic conductivity with depth in peat. However, even Boelter (1965) found that poorly decomposed *Sphagnum* and woody peat with relatively high hydraulic conductivities can occur at depths of over a metre below a bog surface. It should also be noted that Päivänen conducted his study on drained peats which may not be representative of the conditions in undisturbed bogs to which Armstrong's analysis applies (Päivänen, 1973, p. 18).

In further support of the possibility of an exponential decline in hydraulic conductivity with depth in peat, Armstrong notes:

> Baird (1995) suggests the interesting hypothesis that the entrapment of methane within pores can produce an *inverse* [our italics] relationship between the hydraulic conductivity of a peat soil and the pore-water pressure, and this would then produce an exponential decline of effective conductivity with depth without requiring any additional change in peat properties.

The hypothesis he refers to was actually developed by Baird and Gaffney (1995) and is summarized in Baird (1995). Armstrong's statement, in particular the claim that Baird and Gaffney's hypothesis gives an inverse relationship between hydraulic conductivity and depth, shows a misunderstanding of the equation presented in Baird and Gaffney (1995).

Baird and Gaffney (1995) note that there is a growing body of evidence for the entrapment of methane gas bubbles below the water table in peat soils. These bubbles block pores within the peat and cause a reduction in hydraulic conductivity. Based on data presented by Reynolds *et al.* (1992), Baird and Gaffney (1995) suggest that the relationship between hydraulic conductivity (K) and undissolved gas volume below the water table can be given by:

$$K = K_s e^{-\omega\gamma} \tag{1}$$

where K_s is the true saturated hydraulic conductivity of the peat (m s^{-1}), γ is gas volume per unit volume of peat (m^3 m^{-3}), and ω is an empirical constant dependent on peat type.

Baird and Gaffney (1995) point out that changes in pore water pressure as the water table rises and falls will cause methane gas bubbles respectively to contract and expand. K will in turn increase and decrease. Recognizing this, it is possible to express the relationship between K and pore water pressure by substituting Boyle's Law into Equation 2 to give:

$$K = K_s e^{-\omega\gamma_a \frac{u_a}{u_a + u_p}} \tag{2}$$

where γ_a is the volume of undissolved gas held in the peat assuming atmospheric pressure and is therefore a surrogate for undissolved gas content (in moles), and u is pressure (Pa), the subscripts a and p referring to atmospheric pressure and pore water pressure respectively.

Equation 2 is the relationship Armstrong (1995) refers to. Contrary to an inverse relationship suggested by Armstrong, Equation 2 will give a *direct* relationship between K and depth. Pore water pressures increase with depth below the water table. Thus for the same undissolved gas content, the value of the quotient $u_a/(u_a + u_p)$ in Equation 2 will decrease giving a higher value of K. In addition the relationship in Equation 2 is not simply exponential, as Armstrong implies, because of the appearance of this quotient. Baird (1995) and Baird and Gaffney (1995) present graphs showing the form of the increase in K with total pressure $(u_a + u_p)$.

Equation 2 could be used in either a steady-state or transient groundwater model similar to that of Armstrong in which the mire is conceptualized as a set of vertical slices or computational cells. For each of these computational cells the mean hydraulic conductivity ($\bar{K}$) over the depth of the mire below the water

table needs to be calculated. This can be written as:

$$\bar{K} = K_s \frac{\int_{\xi_a}^{\xi_d} e^{\omega\gamma_a\xi} d\xi}{\xi_d - \xi_a} \tag{3}$$

where $\xi = u_a/(u_a + u_p)$ giving $\xi = 1$ when $u_p = 0$, and d refers to the distance to the base of the mire from the water table. Equation 3 can be readily integrated.

Equation 2 has not been tested experimentally and any model using it should be used with caution. A model of hydraulic conductivity of peats should also consider the effects of matrix swelling and compression on pore structure and conductance. Swelling and compression are caused by changes in effective stresses due to water table rise and fall (Baird and Gaffney, 1994; Baird, 1995) and are also affected by the buoyancy exerted on the solid phase by gas bubbles below the water table.

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